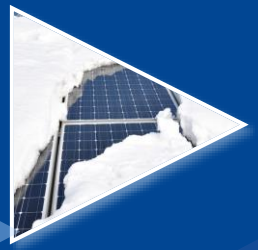


COST PEARL PV

WG4 Workshop: Photovoltaic Systems in the Built Environment

Solar Energy in Nordic Built Environments: Opportunities, challenges and barriers

Digital Workshop 19.01.2022

Gabriele Lobaccaro

Associate Professor

E-mail: gabriele.lobaccaro@ntnu.no

NTNU | Kunnskap for en bedre verden

What do I wish you to remember from the presentation?

- **The solar energy potential exists in any latitudes and climates**
- **The solar energy potential can be calculated and optimized at the building and neighborhood level**

SOLAR ENERGY POTENTIAL

01

The solar energy potential and solar radiation components

- Solar energy potential
- Opportunities for the solar energy potential in different latitudes

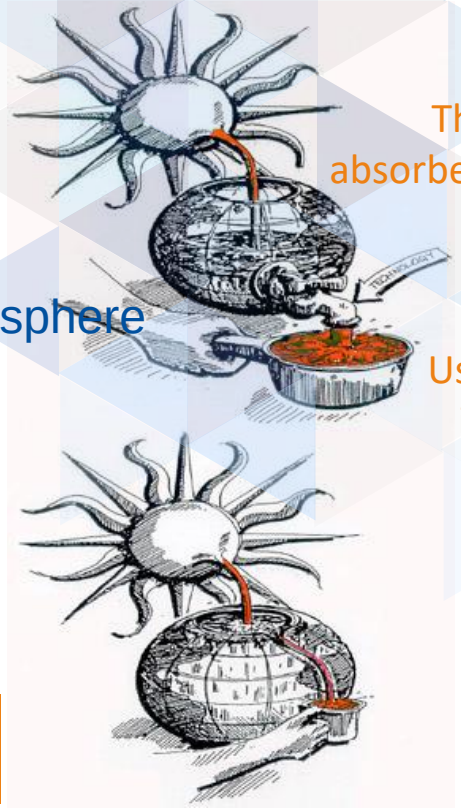
Cities…

Reference: Rex Features

What shall we do?

- Reduce energy consumption
- Reduce CO_2 emissions into the atmosphere
- Implementation of renewable energy

+ **Maximize solar energy**



The total solar energy absorbed from the earth is equal:

3,850,000 EJ

Use of primary energy in 2019 was equal:

510 EJ

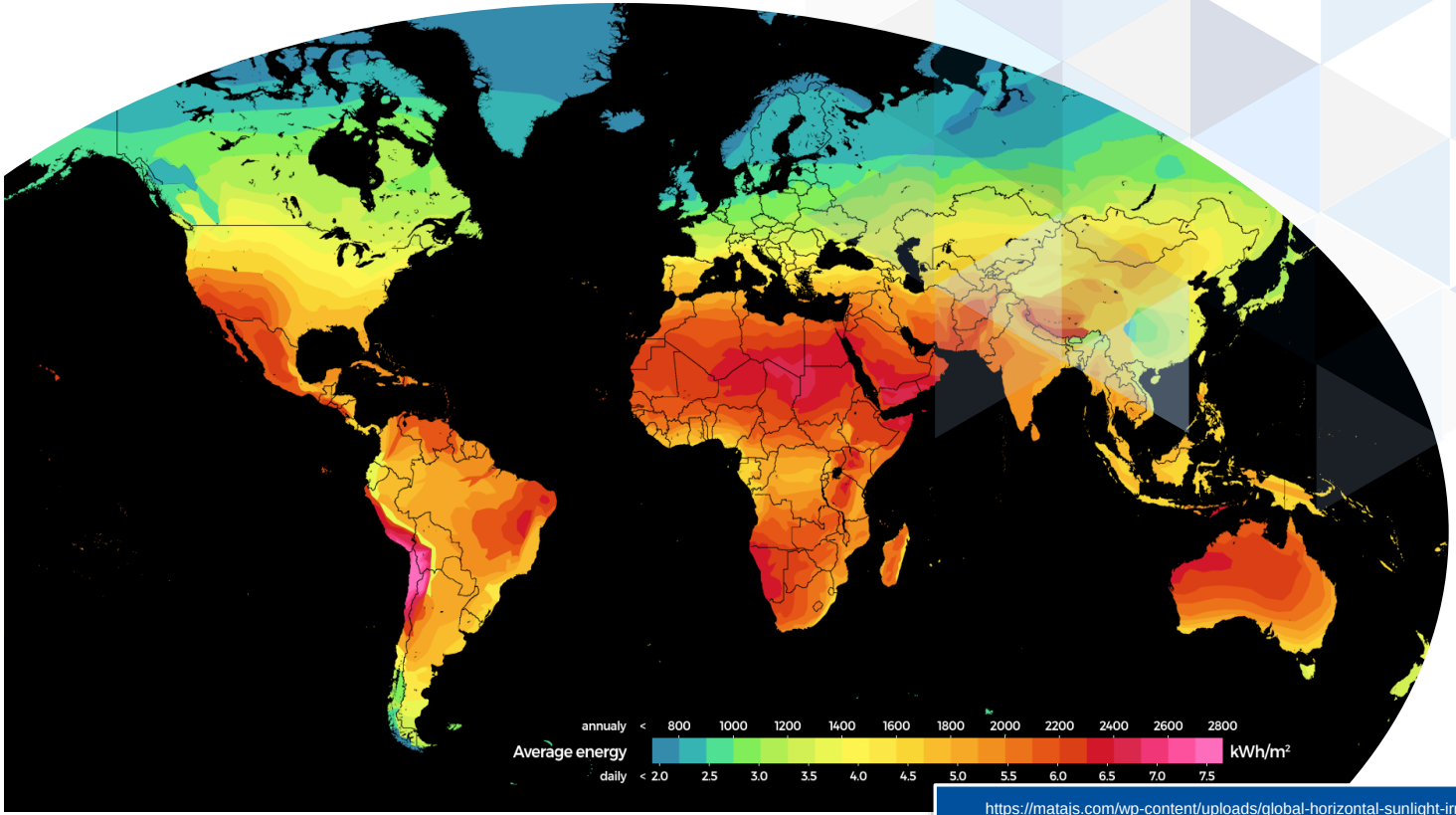
Electricity:

62EJ

International Energy Agency

Reference: International Energy Agency

Solar energy potential in the world



https://matajs.com/wp-content/uploads/global-horizontal-sunlight-irradiation-kwh-year-day.png

PV Landscape in Nordic climate

Solar radiation

Amibient temperature

Wind speed

Meteo data

Reference: fjordkraft.no

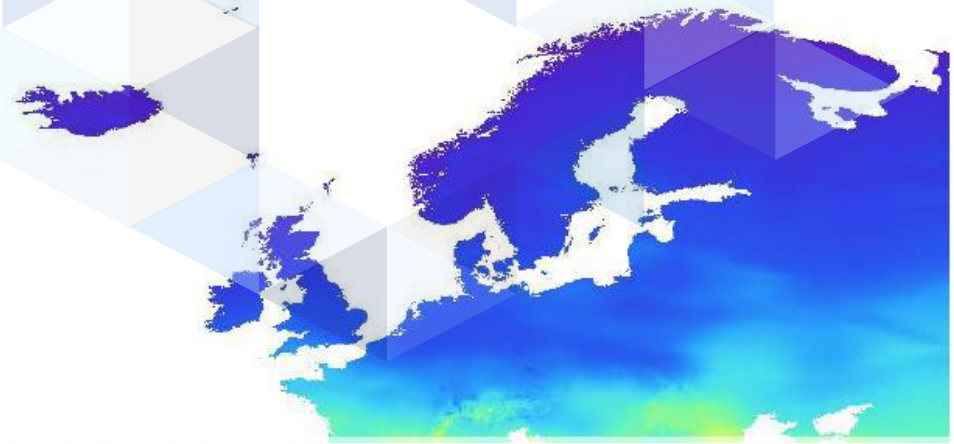
CHALLENGE SOLAR

i nordiske klima!

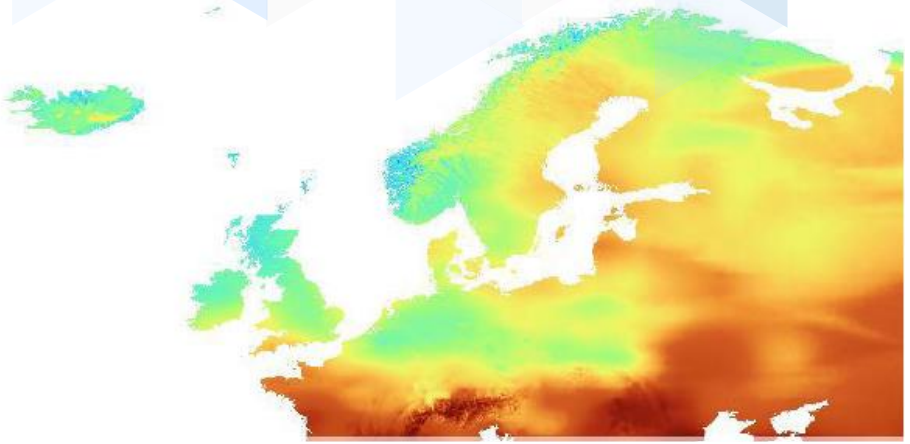
Solar energy potential

NorthSol Solar Power Plants in the Nordic Climate
Common notions and myths

- Too little sunlight — FALSE
- Too expensive — FALSE
- Too cold — FALSE: Lower temperature gives higher efficiency



Solar radiation on a horizontal surface (kWh/m²år)



Solar radiation on a 2-axis solar tracking surface (kWh/m²år)

Solar energy potential

Annual hours of sunshine - all over the world

Country	City	Annual Sun Hours
UK	London	1500
Germany	Freiburg	1700
Sweden	Piteå	2000
Australia	Melbourne	2100
Italy	Florence	2500
USA	San Diego	3000

Reference: Norden

Solar cells in the Nordic climates

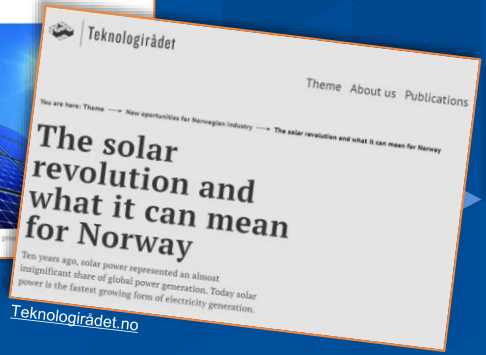
Framtida.no

Fjordkraft.no

Nrk.no

Gemini.no

Pv-magazine.com



Teknologirådet.no

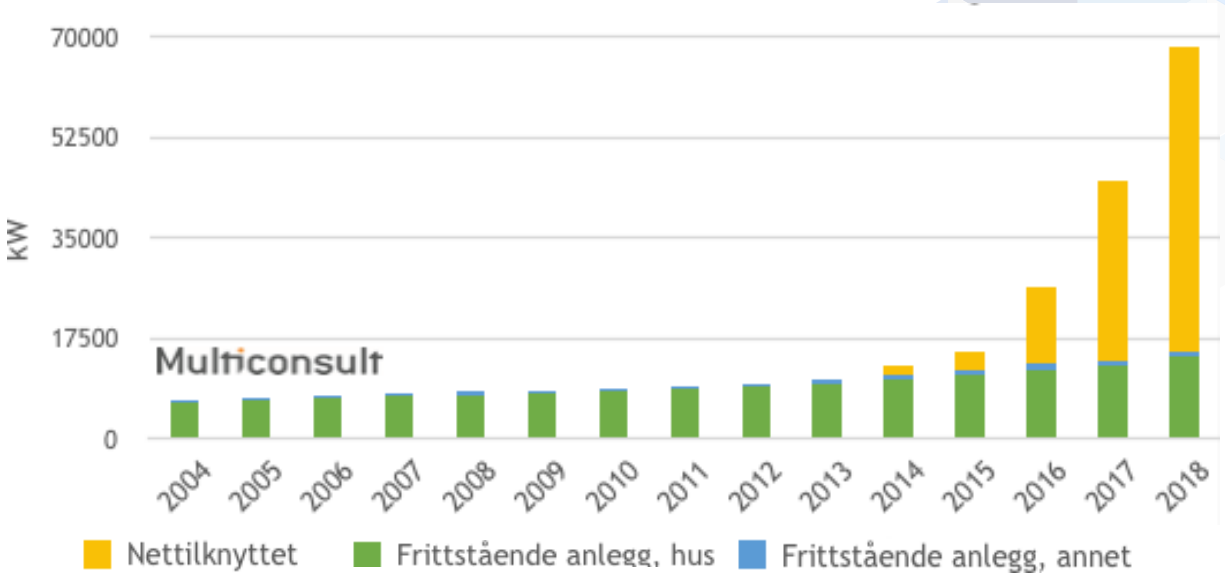
NyttNorge.com

Nrk.no

Referanse: flere

Solar installation in Norway

Akkumulert installert effekt i Norge



Referanse: solenergiklyngen.no og multiconsult.no og tu.no

SOLAR ENERGY AND INTEGRATION OF SOLAR CELL SYSTEMS FROM BUILDING LEVEL TO NEIGHBORHOOD LEVEL

02

Solar cells at building level and neighborhood level

- Problems and strategies
- Case studies and simulation tools

Building Integrated Photovoltaic (BIPV)

+ Primary weather protection: rain, snow, wind, hail

+ Noise protection

Adlershof Scientific Park
Berlin - Germany

Frodeparken
Uppsala - Sverige

+ Safety

deltaZERO,
Lugano - Switzerland

+ Daylighting

+ Energy economy

+ Distinguish between indoor and outdoor environments

+ Structural integrity

+ Mechanical rigidity

Lyon Confluence
france

Brise-soleil photovoltaïque «Le Albere» , Trento - Italy

+ Shading systems

+ Thermal insulation

+ Fire protection

Reference: International definitions of «BIPV»

Integration of solar cells in building level

Reference: Plan og Bygningsloven (PBL), huseierne.no og solenergi.no

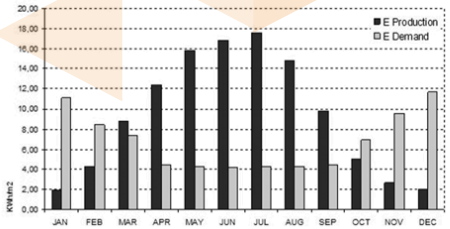
Case studies of BIPV at Gløshaugen Campus

Elektrobygg

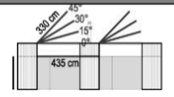
ZEB test Cell

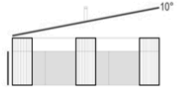
ZEB Office Living Laboratory

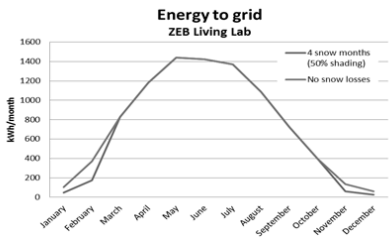
ZEB Residential Living Laboratory



Model		KWh/y	KWh/y m2
M-1	0°	8745	82,2
	15°	9736	91,5
	30°	10004	94,0
M-2	0°	12798	120,3
	10°	13903	130,66
	20°	14732	138,4

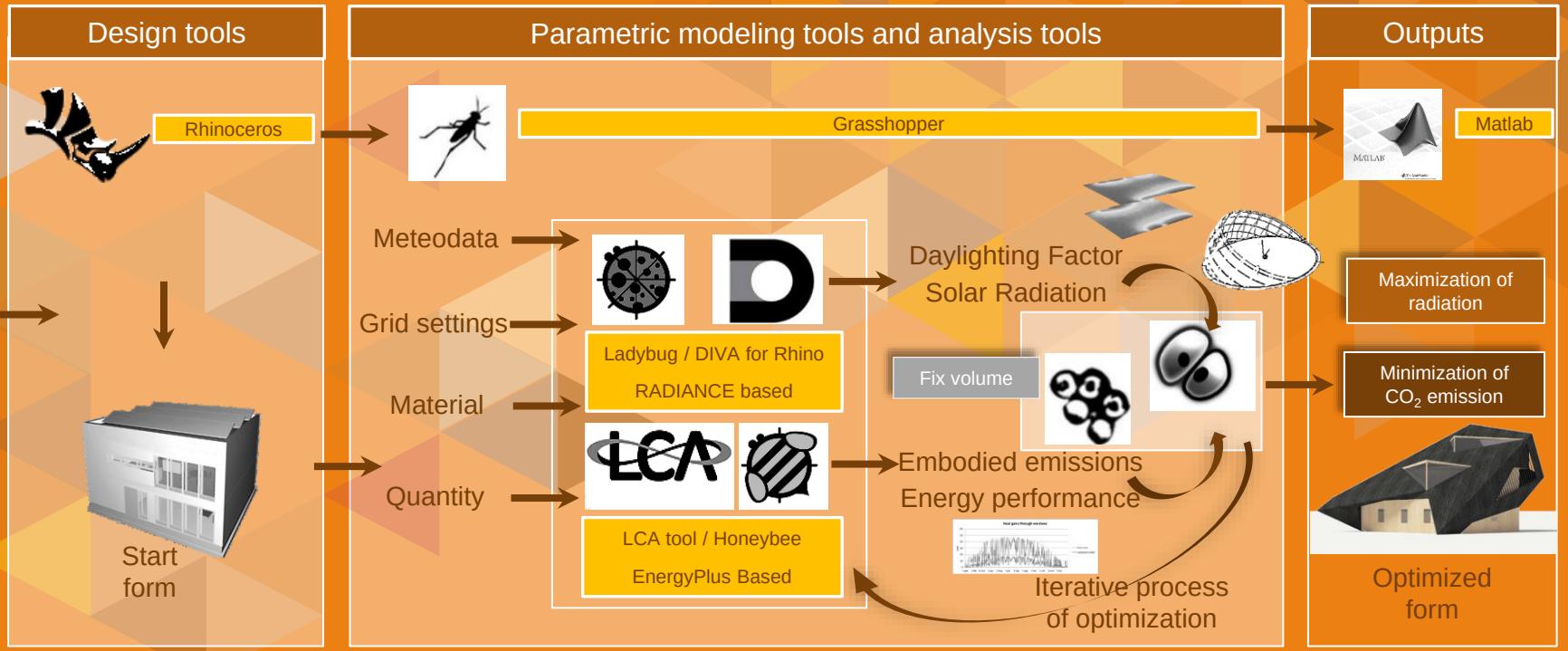






Referanse: Luca Finocchiaro - Bilder: Ruth Woods

Optimization of building shape and surface exposure

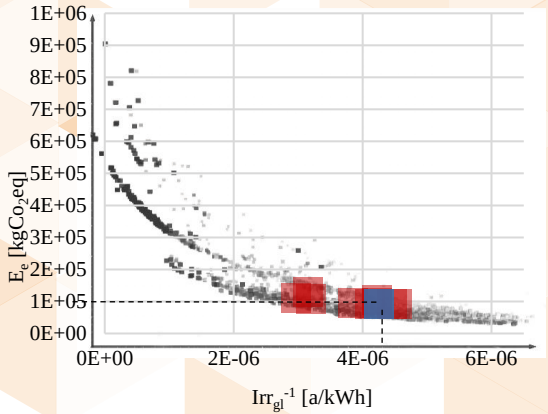


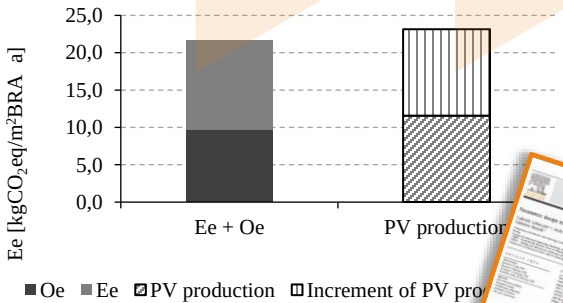
Workflow with design and simulation tools

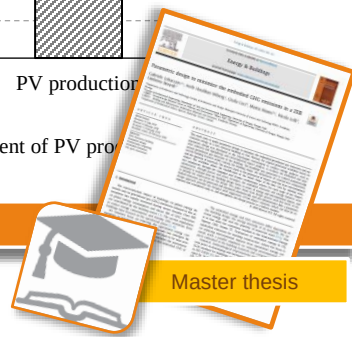
Optimization of building shape and surface exposure

Octopus output	Irr_{gl} [kWh/a]	E_e [kg CO_2eq]	Shape	Octopus output	Irr_{gl} [kWh/a]	E_e [kg CO_2eq]	Shape
Output 1	243,300	93,000		Output 6	220,400	92,000	
Output 2	234.500	92,000		Output 7	237,200	104,350	
Output 3	237,100	93,800		Output 8	312,600	106,000	
Output 4	259,650	96,200		Output 9	336,600	108,950	
Output 5	224,500	91,450		Output 10	317,450	128,000	

Up to the **80%** of the shell should be covered by PV panels in order to achieve the ZEB-OM ambition level







Reference: Lobaccaro G., Wiberg A.H., Ceci G., Manni M., Lolli N., Berardi U., Parametric design to minimize the embodied GHG emissions in a ZEB, Energy and Buildings 167, (2018), pp. 106-123.

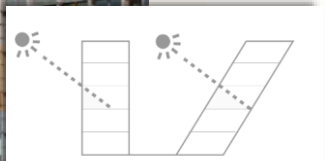
Optimization of solar buildings

Isolated building optimization

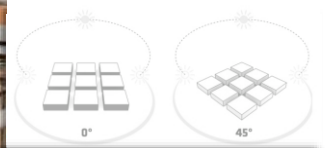
Reference: Flere

Solar strategies at the neighborhood level

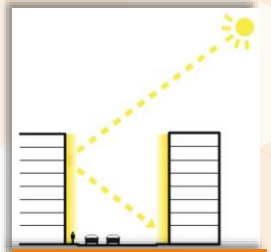
Sorrounding landscape



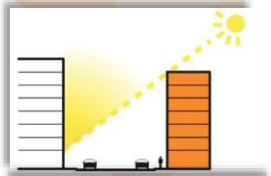
The depth of the spaces
% of glazed facades



Neighborhood orientation



Solar reflection



Solar accessibity

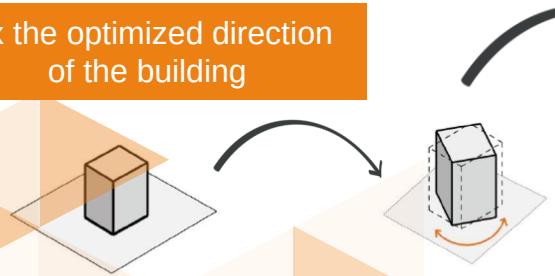
Overshadowing

Reference: London (Bildet: Gabriele Lobaccaro)

Solar accessibility and Solar reflections

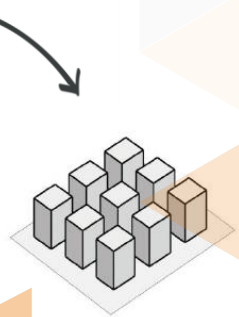
Solar energy from building level to neighborhood level

Fix the optimized direction of the building



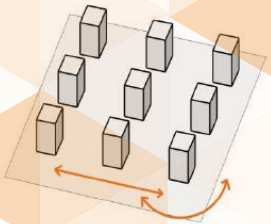
isolated scenario

Calculation of direct radiation

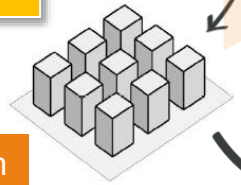


Urban scenario

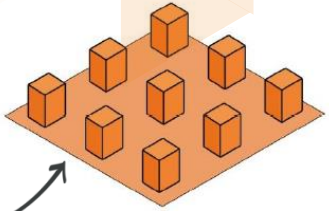
Calculation of direct radiation



Optimize the orientation of the neighborhood



Fix the optimized direction of the neighborhood



Study interactions between solar energy

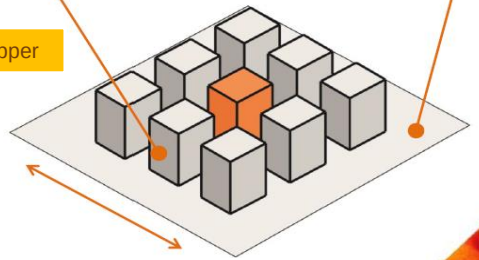
Calculation of global (direct + diffuse + reflected) solar radiation

Case study of solar energy potential

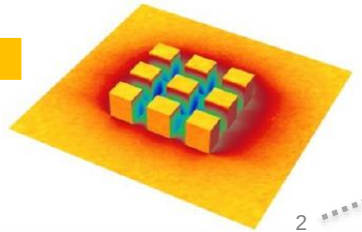
Albedo of facades (reflection coefficient)

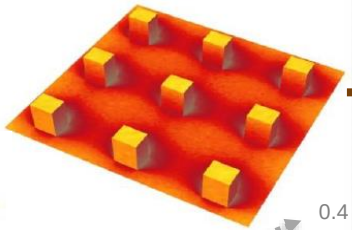
Albedo of the ground (reflection coefficient)

Rhinoceros + Grasshopper



Ladybug + DIVA for Rhino



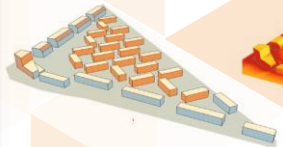


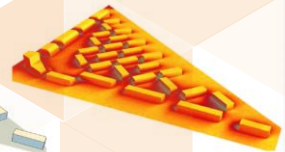
0.4

2

1- Simple district

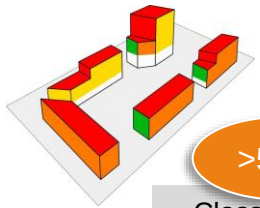
Guidelines for master plan





Optimized configuration and energy analyzes

umi



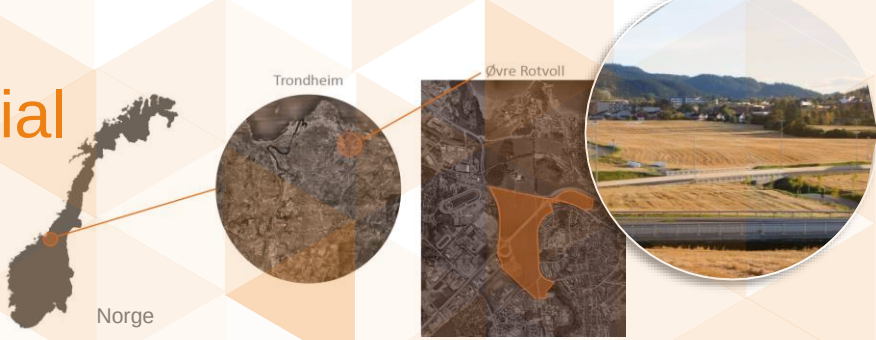
>55%

Class A

2- Complex district

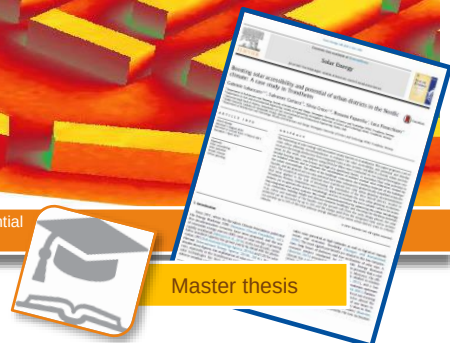
Reference: Lobaccaro G., Carlucci S., Croce S., Paparella R., Finocchiaro L., Boosting solar accessibility and potential of urban districts in the Nordic climate: A case study in Trondheim, Solar Energy Vol. 149, (2017), pp. 347-369.

Case study of solar energy potential in Norway



Masterplan of Øvre Rotvoll

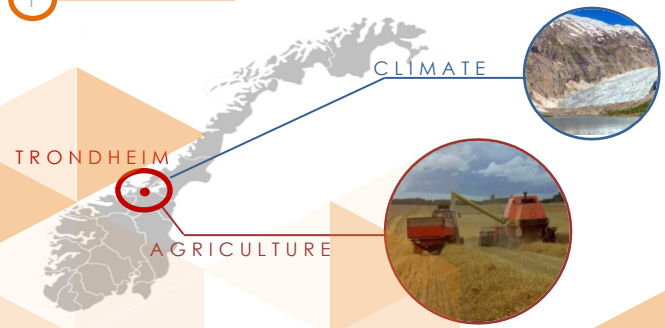
Reference: Lobaccaro G., Carlucci S., Croce S., Paparella R., Finocchiaro L., Boosting solar accessibility and potential of urban districts in the Nordic climate: A case study in Trondheim, Solar Energy Vol. 149, (2017), pp. 347-369.



Master thesis

Analysis of the solar energy potential in the urban area

1 NORWAY

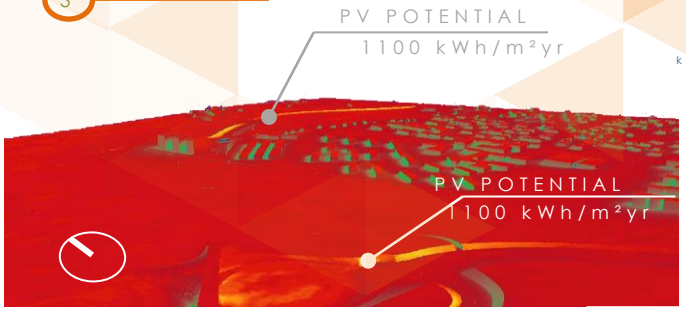


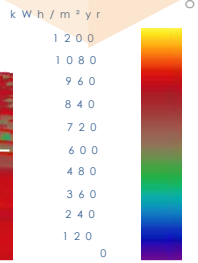
SOLAR POTENTIAL ANALYSIS OF LANDSCAPE

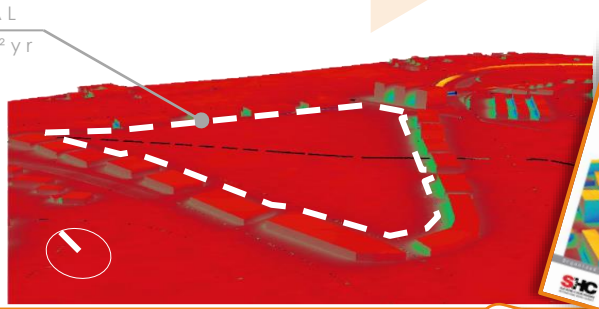
2 EXISTING BUILDING ANALYSIS

SITE DESCRIPTION

3 SCENARIOS

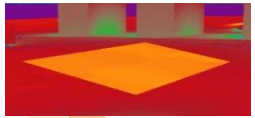






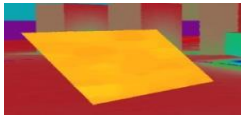
Reference Winter workshop 2015 NTNU/University of La Reunion

Analysis of the solar energy potential in the urban area



PV 0°

860 KWh/m²yr



PV 37,5°

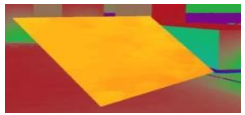
1104 KWh/m²yr

+ 28%

PV 12,5°

987 KWh/m²yr

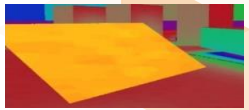
+15%



PV 45°

1115 KWh/m²yr

+29.5%



PV 25°

1065 KWh/m²yr

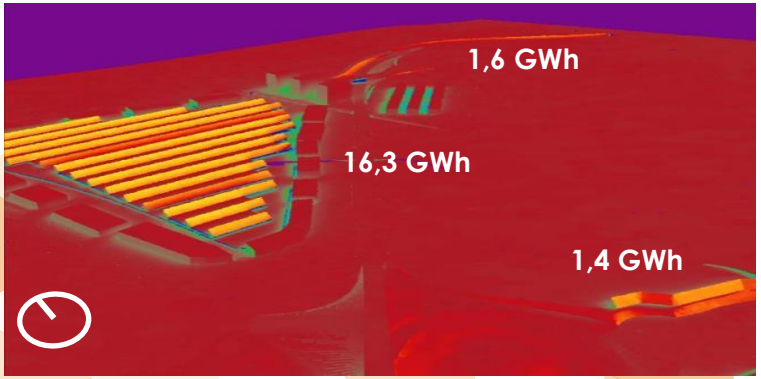
+24%

SUN PATH

AGRICULTURAL FARM

PRINCIPAL ROAD

Solar farm & PV barriers



PV FARM

INSTALLED AREA: 14656 m²

AVERAGE ENERGY: 1115kWh/m²yr

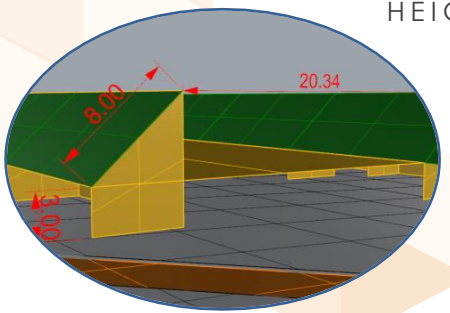
ENERGY TOTAL: **16,3 GWh**

PV ACOUSTIC BARRIER

INSTALLED AREA: 2712 m²

AVERAGE ENERGY: 1115kWh/m²yr

ENERGY TOTAL: **3 GWh**



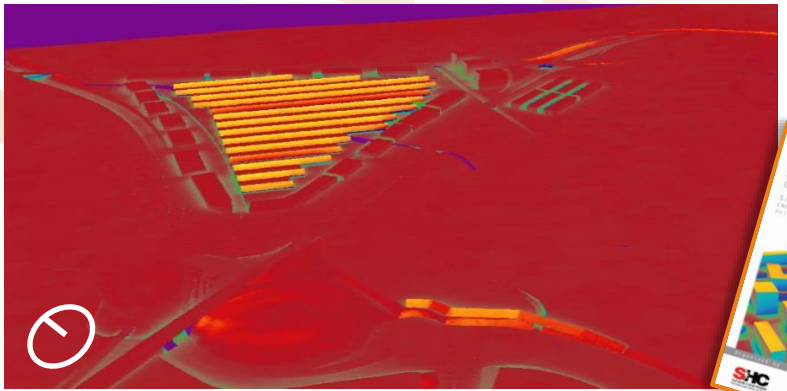
HEIGHT : 3,00 m

PV ANGLE : 45 °

AVERAGE ENERGY:

1115kWh/m²yr

IMPROVEMENT : **30%**



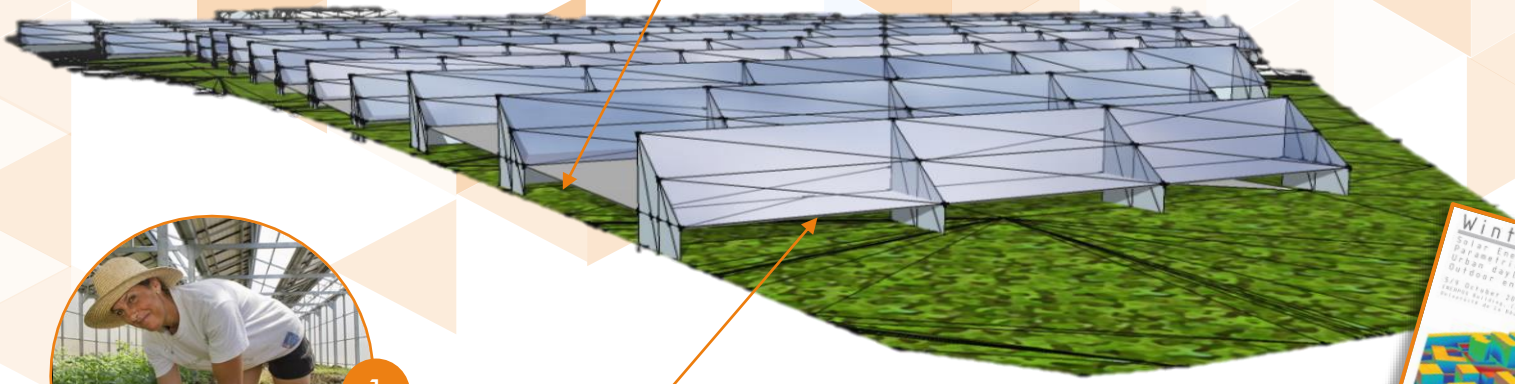
Solar farm & PV barriers

PV FARM

INSTALLED AREA: 14656 m²

ENERGY TOTAL: **16,3 GWh**

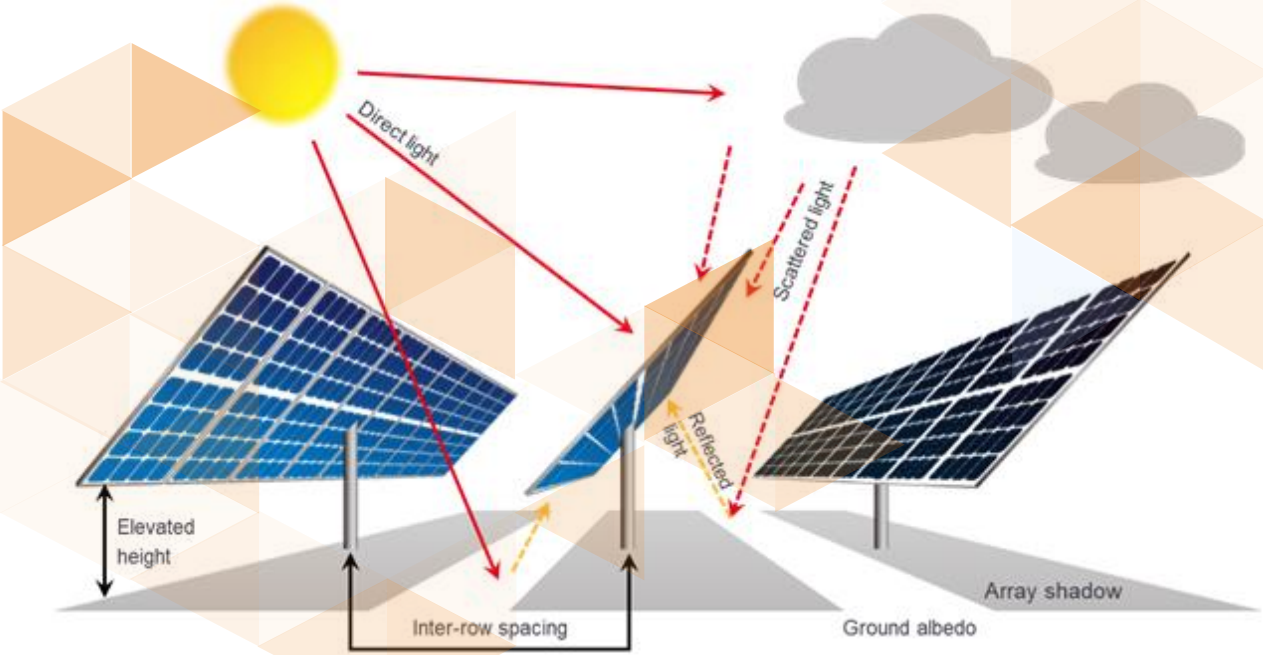
2

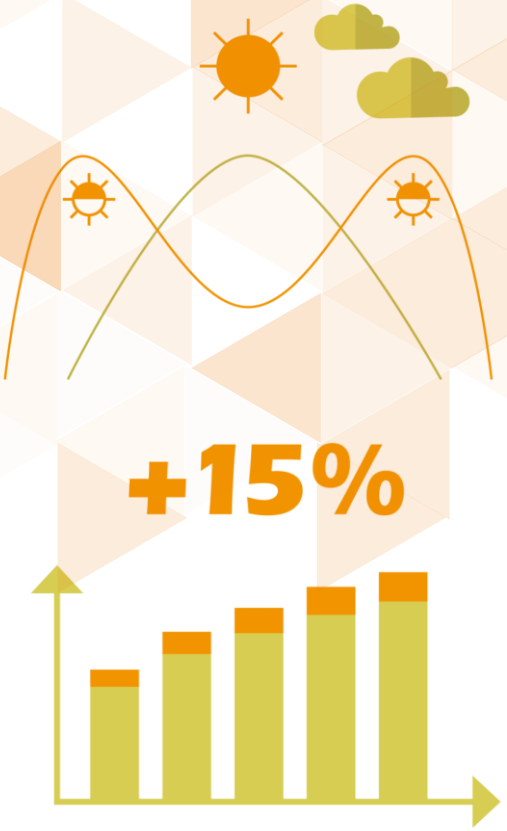


1

AVERAGE ENERGY: 1115kWh/m²yr

Bifacial photovoltaics





Solar farm/AgroPV Bifacial photovoltaics

Reference Next2sun

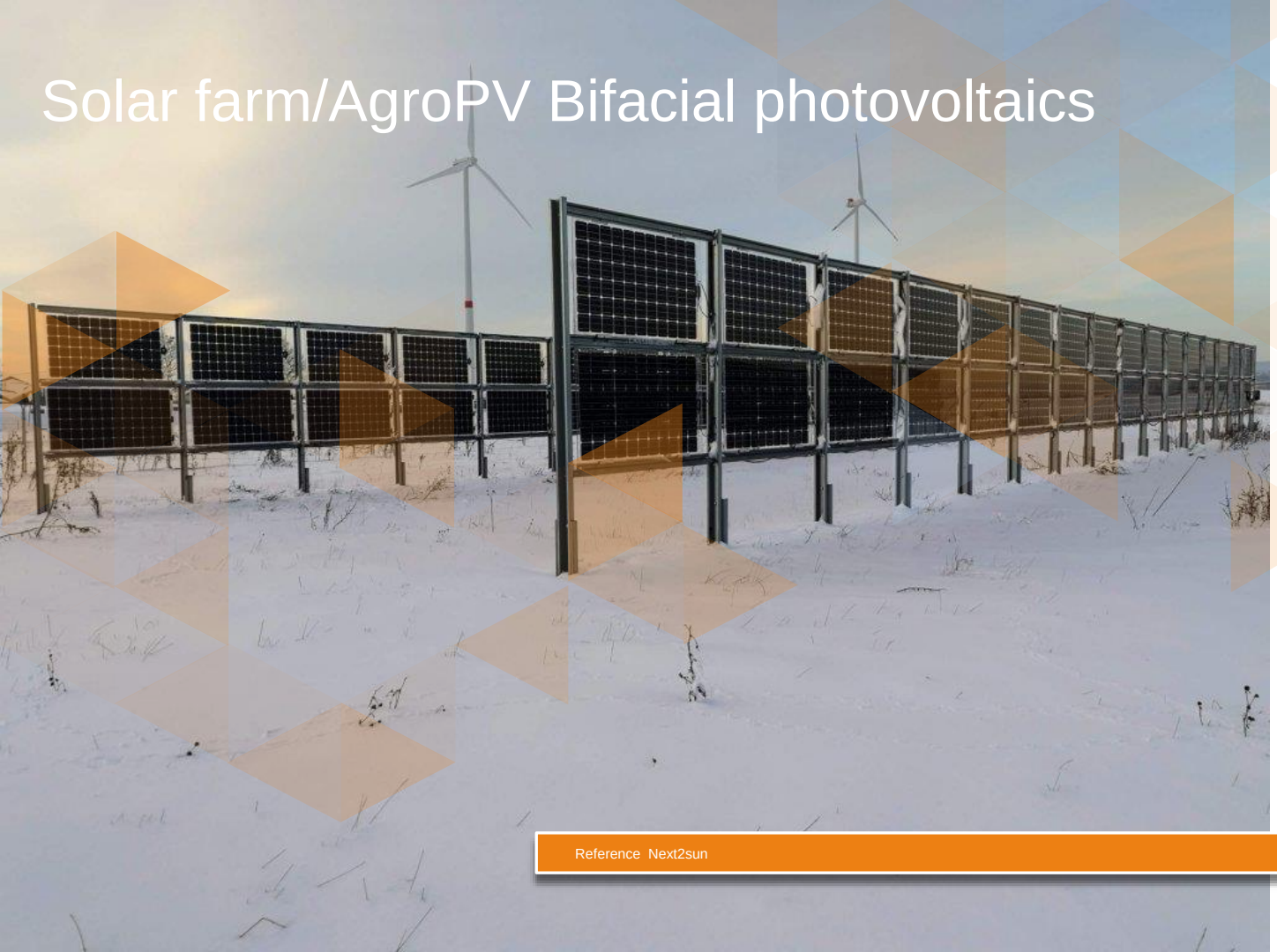
Solar farm/AgroPV Bifacial photovoltaics

Reference Next2sun

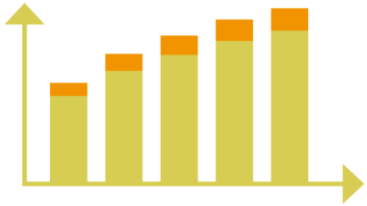
Solar farm/AgroPV Bifacial photovoltaics

Reference Next2sun

Solar farm/AgroPV Bifacial photovoltaics



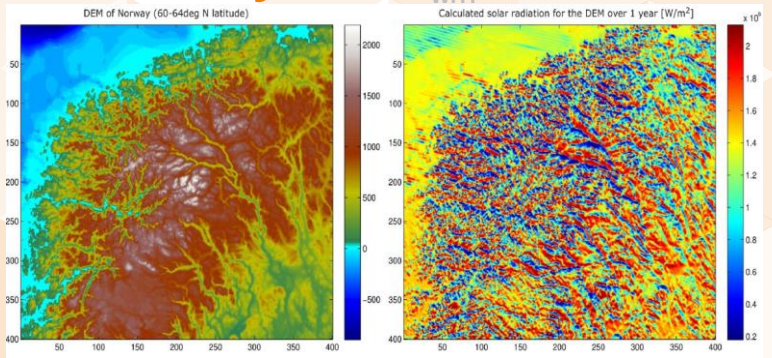
+15%



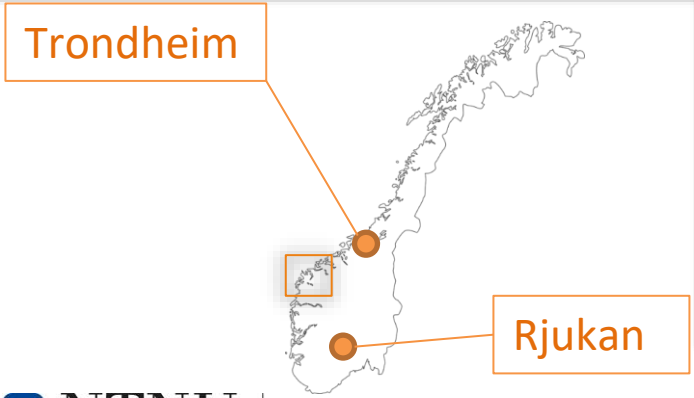
Reference Next2sun

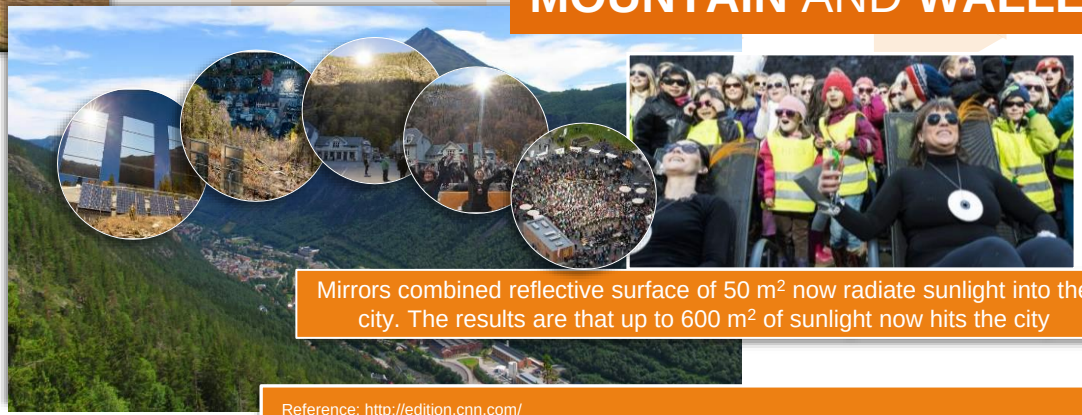
Solar energy potential vs Orography in Norway

FLAT terrain



MOUNTAIN AND **WALLEY**

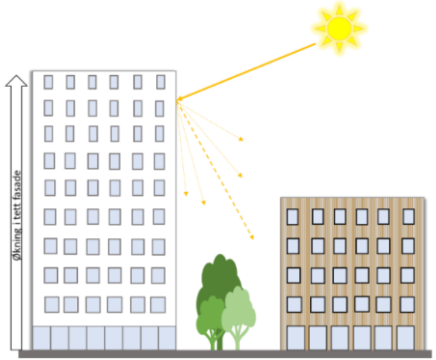




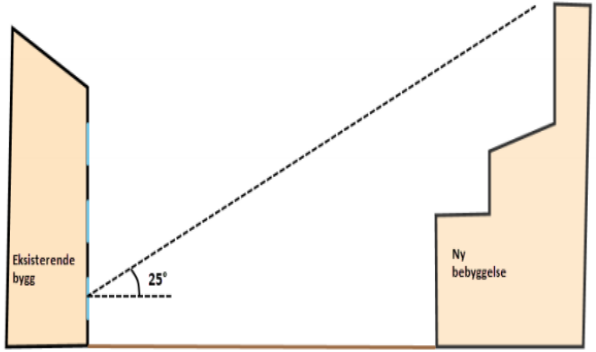
Mirrors combined reflective surface of 50 m² now radiate sunlight into the city. The results are that up to 600 m² of sunlight now hits the city

Reference: http://edition.cnn.com/

Sun reflection in cities - Shielding surroundings



Sorrounding landscape



Figur 4: Eksempel på skjermingsvinkel for eksisterende bygg, for bruk i flytdiagram i Figur 5.

Plan interactions between buildings

Urban planning and regulation

Zoning plan

Referanse: RIF - Dagslys i bygninger

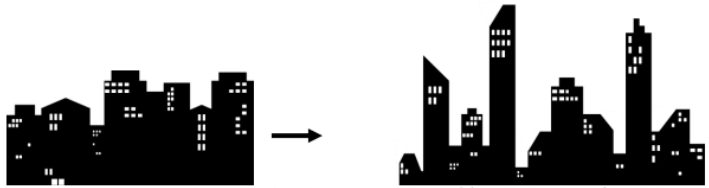
Sun reflection in cities - Shielding surroundings

Theory Practice

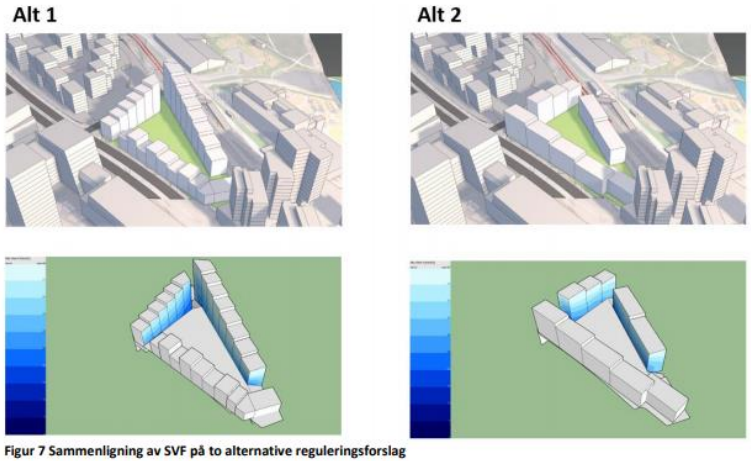
WHAT

WHY

HOW



Figur 2: Illustrasjon av variasjon i bygningshøyder og bygningsmasser, etter Ref. (Kongebro, et al., 2012)



Figur 7 Sammenligning av SVF på to alternative reguleringsforslag

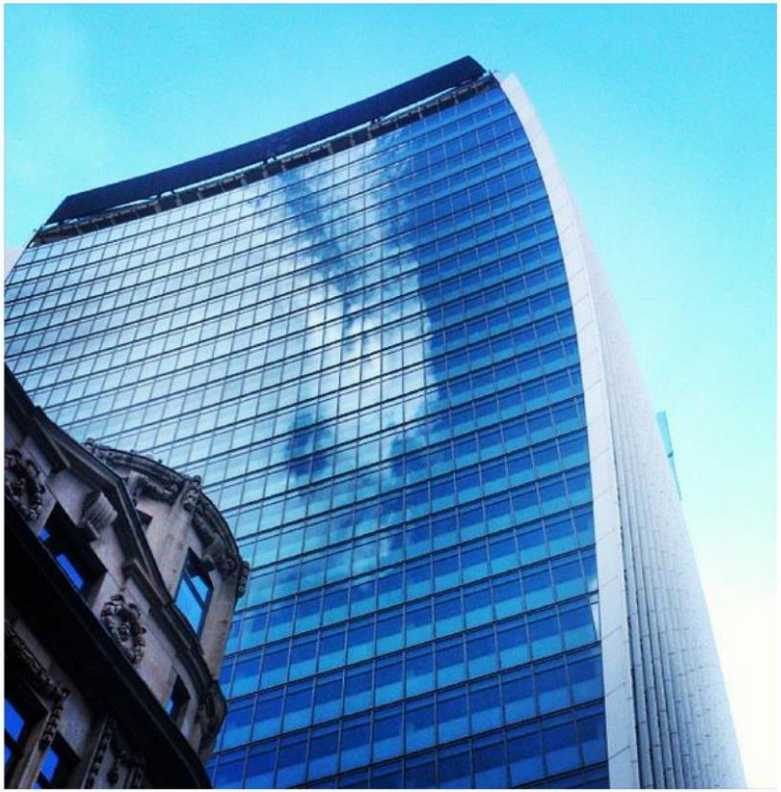
Plan interactions between buildings

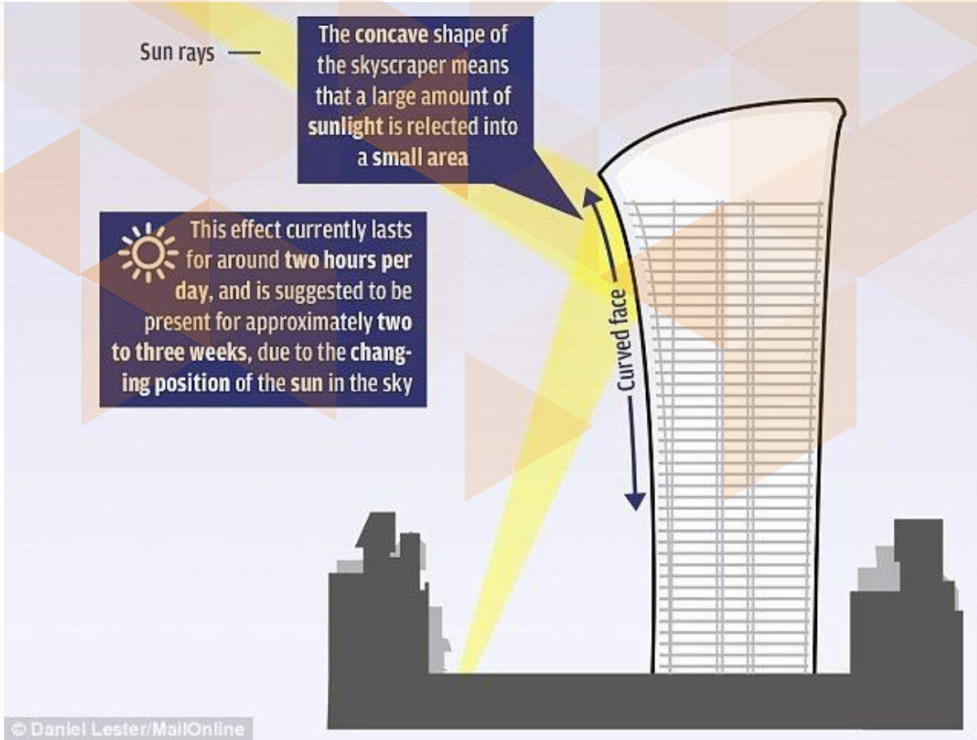
Urban planning and regulations

Zoning plan

Referanse: RIF - Dagslys i bygninger

Sun reflection in cities





Reference: 20 Fenchurch Street (Sky Garden) – London; Photo: Gabriele Lobaccaro

Sun reflection in cities

IL FUTURO DELLA CITTÀ

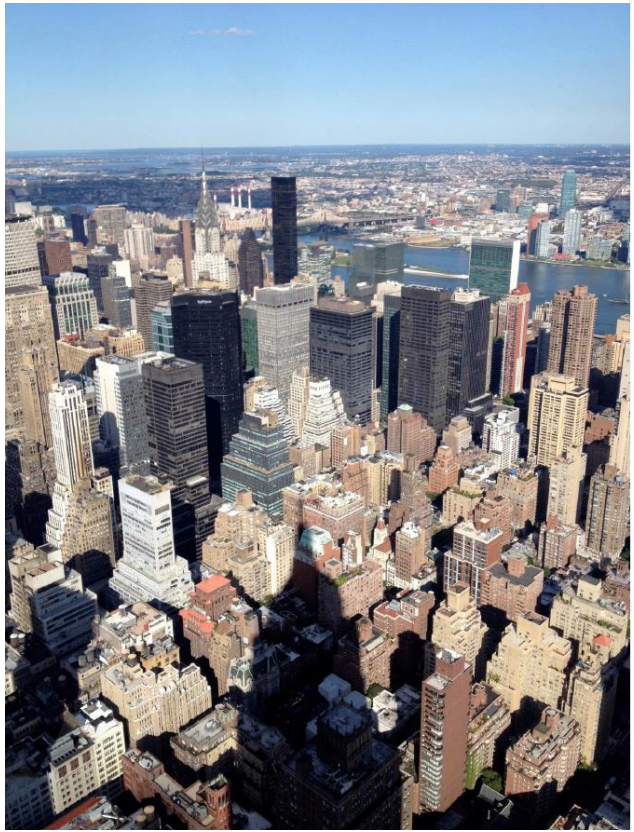
Pirellone bis, le pareti a specchio sciolgono le tapparelle dei palazzi

«P

Referanse: Palazzo della Regione Lombardia – Milan (Italia); Photo: Gabriele Lobaccaro

Overshadowing effect / **S**olar accessibility / **S**olar reflections

Overshadowing effect



Reference: The empire state building- NYC; Burj Khalifa - Dubai

Overshadowing effect

Referanse: São Paulo - Dubai

Overshadowing effect

PREMIER LEAGUE | MA DAI

Chelsea, l'ombra del nuovo Stamford Bridge costa milioni ad Abramovich

I Blues hanno trovato un accordo con una famiglia che abita vicino dello stadio. Al centro della contesa la maggiore ombra che il nuovo impianto proietterà sulla casa

15 MARZO 2018 - MILANO

Il rendering del nuovo Stamford Bridge. Nel riquadro rosso la casa al centro del contenzioso

APPROFONDIMENTI | PIÙ LETTI | PIÙ COMMENTATI


Conte: "Noi sfortunati"


Il Real domina il ranking

Referanse: Chelsea Stadium – London – Gazzetta dello Sport

Overshadowing effect

CORRIERE DELLA SERA

MILANO / CRONACA

IL CASO

Melchiorre Gioia, le vecchie case che non vedranno più la luce

La costruzione di due palazzi «imprigionerà» gli edifici già oscurati da tre lati

di Elisabetta Andreis

Reference: Palazzo della Regione Lombardia – Milan (Italia) – Corriere della Sera

Solar systems in the Lerkendal district

View of the area from the top- Reference: google maps og flere

Data of photovoltaic facade:

- 200 m2 South and West facades;
- 27.2 kWp, 9 strings;
- Annual production: 18 000 kWh;
- Actual production (2013): 15 000 kWh (+15%simulated)

Data of the building:

- Building area: 11 000 m2;
- Annual consumption 84 kWh/m2 - Energy class A.
- Connected to district heating and power grids.

Destination of the district and functions:

- Sports facilities,
- Commercial buildings
- Service warehouse

Solar systems in the Lerkendal district

How to avoid and prevent these situations?

View from the top of Lerkendal Studentby - Reference: http://www.adressa.no/

Analysis using dynamic simulations

1: Local solar potential (isolated scenario)

2: Local solar potential (urban scenario)

DIVA FOR RHINO
ENVIRONMENTAL ANALYSIS FOR BUILDINGS

DiVA for Rhino
Based on Radiance ray-tracing method

DAYSIM
ADVANCED DAYLIGHT SIMULATION SOFTWARE

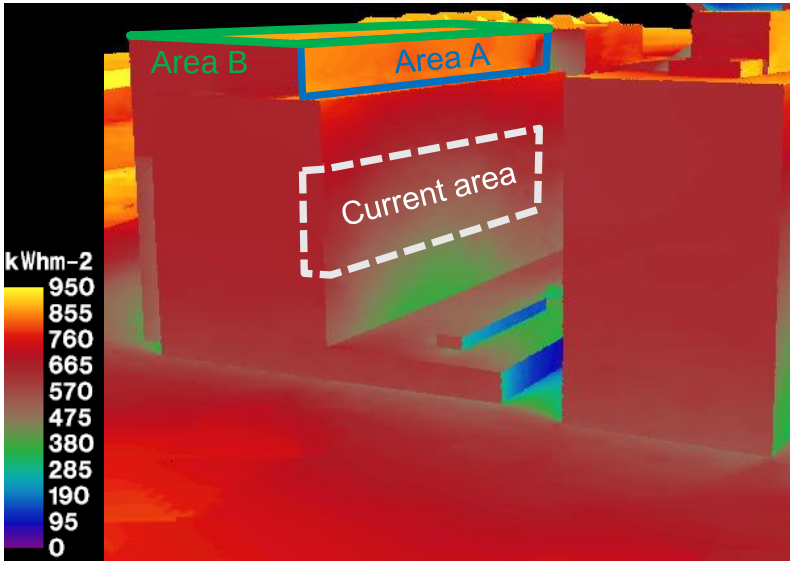
3: Energy production

PVsyst
PV simulation

Polysun
Solar thermal

Referance: Good C.S., Lobaccaro G., Hårklau S., Optimization of solar energy potential for buildings in urban areas - a Norwegian case study, Energy Procedia, Volume 58 (2014) pp 166-171

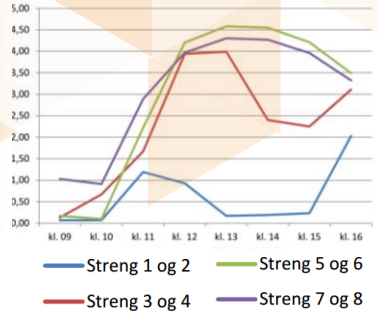
Overshadowing effect and availability on solar energy



Figur 66: 4.april 2014, kl.09:00

Figur 67: 4.april 2014, kl.10:00

Energy production [kW] – 4. April



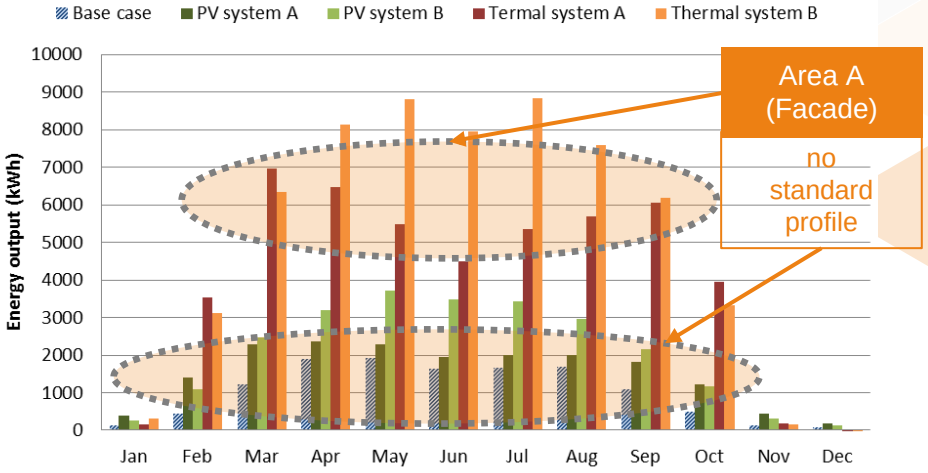
Vekselretter	Strenger	Kl.09	Kl.10	Kl.11	Kl.12	Kl.13	Kl.14	Kl.15	Kl.16
1	1 og 2	0,07	0,07	1,19	0,93	0,17	0,19	0,23	2,03
2	3 og 4	0,13	0,67	1,67	3,94	3,99	2,40	2,25	3,11
3	5 og 6	0,17	0,10	2,22	4,20	4,58	4,55	4,21	3,49
4	7 og 8	1,03	0,91	2,89	3,97	4,30	4,27	3,96	3,32

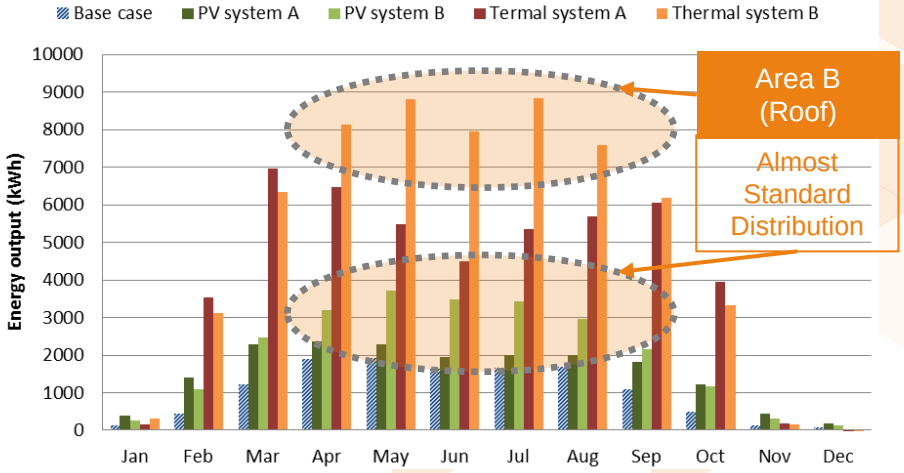
-50 % Direct irradiation (PV facade)

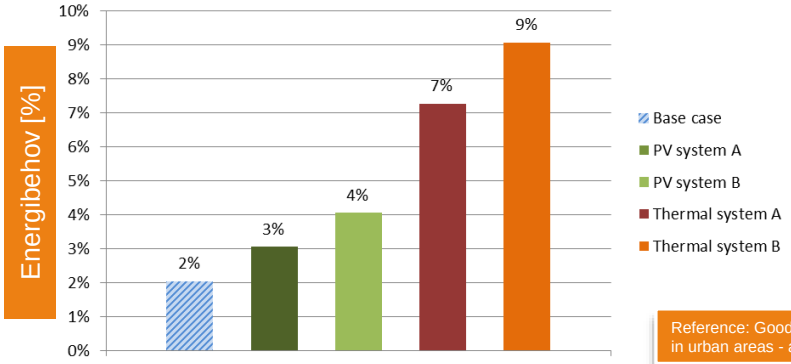
-40 % Global irradiation (PV facade)

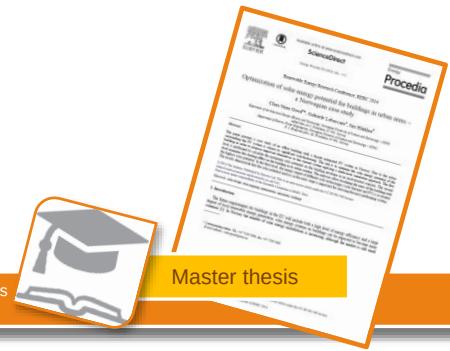
Reference: Good C.S., Lobaccaro G., Hårklau S., Optimization of solar energy potential for buildings in urban areas - a Norwegian case study, Energy Procedia, Volume 58 (2014) pp 166-171

Overshadowing effect and availability on solar energy





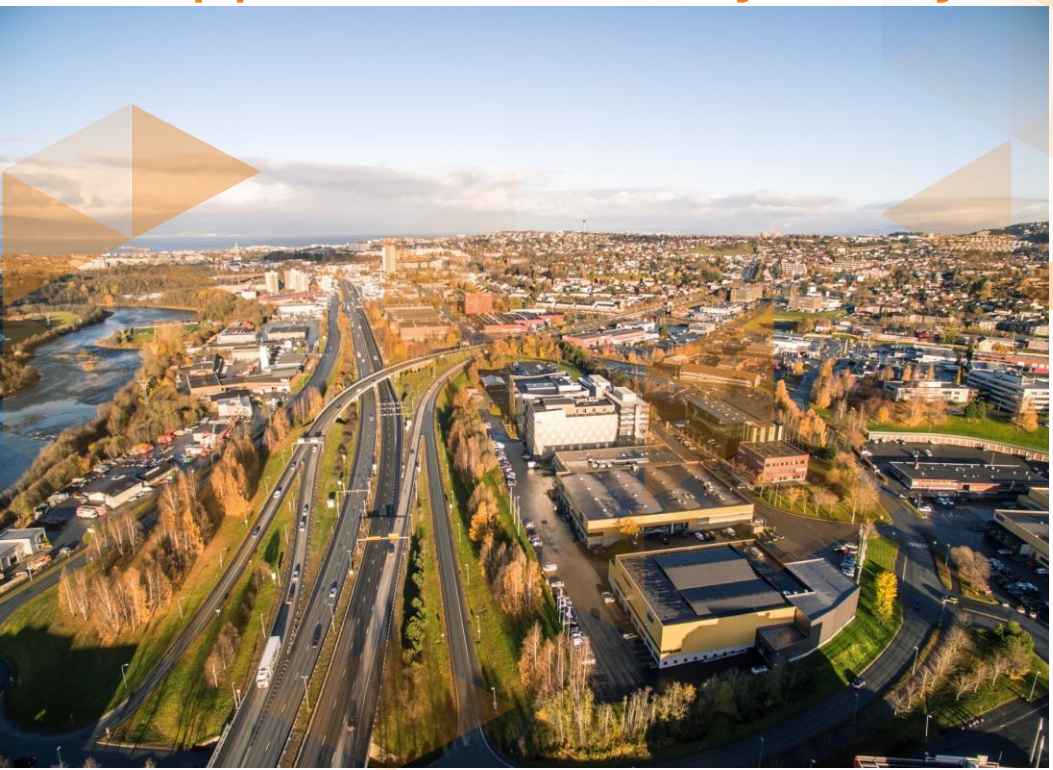


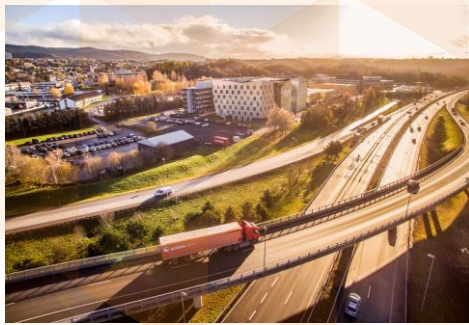


Reference: Good C.S., Lobaccaro G., Hårklau S., Optimization of solar energy potential for buildings in urban areas - a Norwegian case study, Energy Procedia, Volume 58 (2014) pp 166-171

Solar energy potential

Sluppen – Feasibility study….2050?

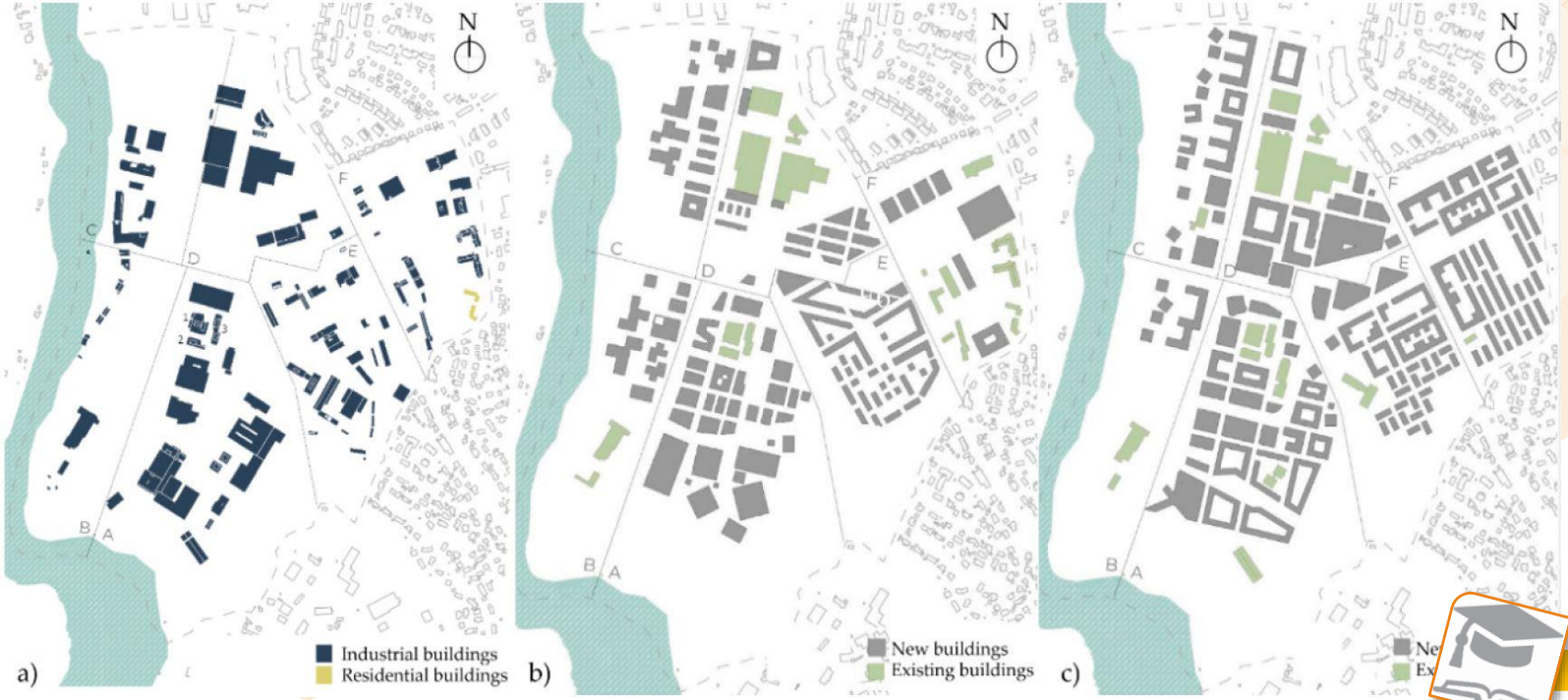




Referanse: Trondheim Kommune

Sluppen – Feasibility study….2050?

New and existing buildings in existing situation (a) Feasibility study I (b) and II (c)

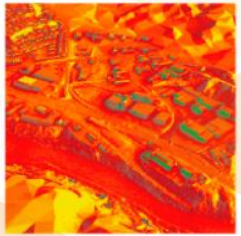
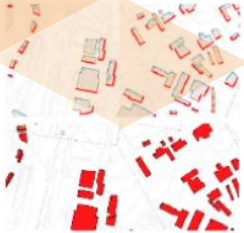
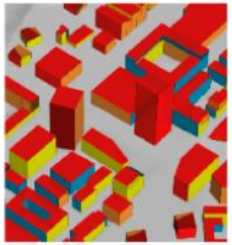
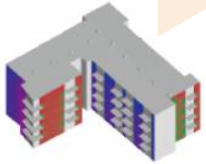


Master thesis

Reference: Lobaccaro, G.; Lisowska, M.M.; Saretta, E.; Bonomo, P.; Frontini, F. A Methodological Analysis Approach to Assess Solar Energy Potential at the Neighborhood Scale. Energies 2019, 12, 3554

Sluppen – Feasibility study….2050?

New and existing buildings in existing situation (a) Feasibility study I (b) and II (c)

	Step 1 Urban analysis	>>	Step 2 Solar radiation analysis	>>	Step 3 Solar mapping	>>	Step 4 Data processing	>>	Step 5 Definition of archetypes & Reduction factors	>>	Step 6 Solar potential, solar energy generation analysis and technology recommendations
Inputs	m² available area H/W height/width ratio between the buildings H building heights roof types shading analysis		- radiation map - radiation analysis at neighborhood scale (annual and seasonal)		- average values of solar radiation on the roofs andon the facades of the buildings		- analysis of area (m²) of building envelop grouped according to solar potential		- calculation of real available area for solar systems		- solar grid-based analysis of solar radiation - solar technologies recommendations
Outputs											
Tools	- Rhinoceros + Honeybee - Revit - Excel		- Diva-for-Rhino		- Revit		- Rhinoceros + Grasshopper - Excel		- Diva-for-Rhino - Excel - Autocad		- Diva-for-Rhino - Excel

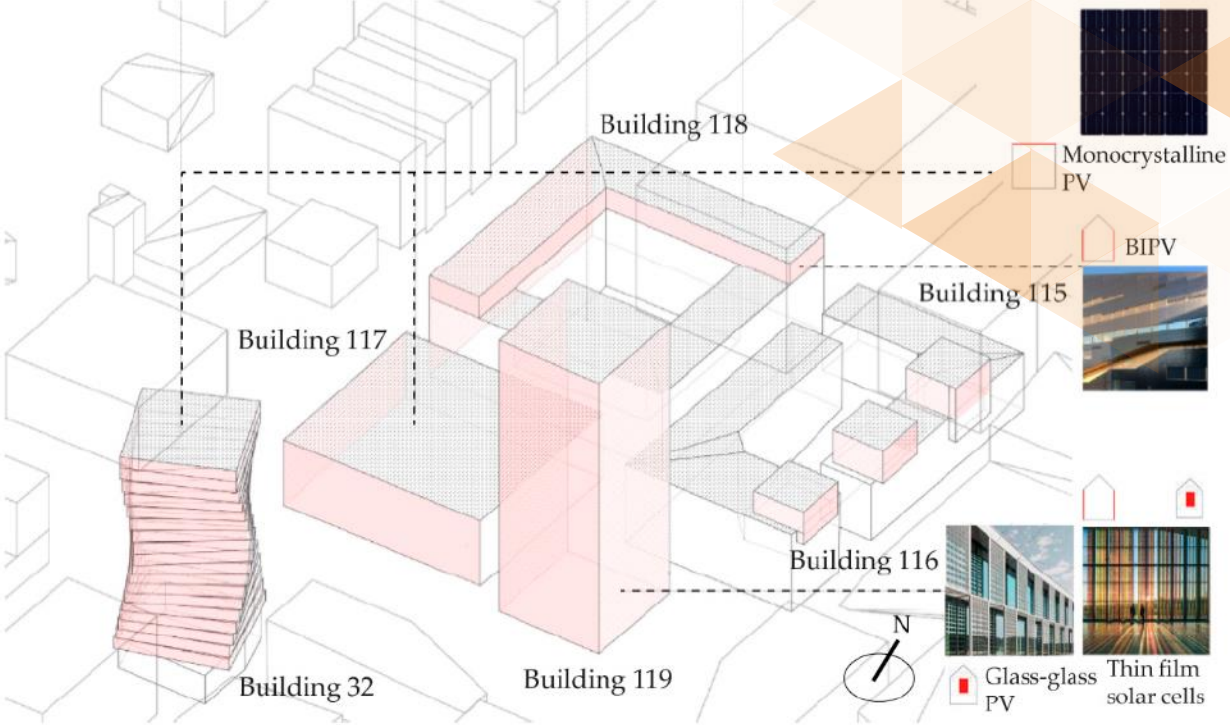
Reference: Lobaccaro, G.; Lisowska, M.M.; Saretta, E.; Bonomo, P.; Frontini, F. A Methodological Analysis Approach to Assess Solar Energy Potential at the Neighborhood Scale. Energies 2019, 12, 3554

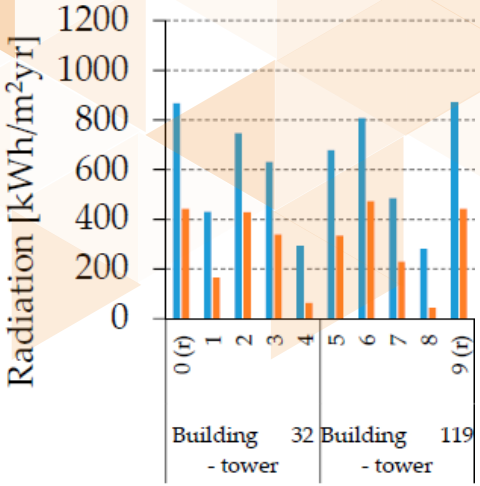
Reduction factors

Reference: Lobaccaro, G.; Lisowska, M.M.; Saretta, E.; Bonomo, P.; Frontini, F. A Methodological Analysis Approach to Assess Solar Energy Potential at the Neighborhood Scale. Energies 2019, 12, 3554

Recommendations on solar technology

Recommendations on solar technology for the critical area for the feasibility study II





Reference: Lobaccaro, G.; Lisowska, M.M.; Saretta, E.; Bonomo, P.; Frontini, F. A Methodological Analysis Approach to Assess Solar Energy Potential at the Neighborhood Scale. Energies 2019, 12, 3554

Challenges and lessons learnt

Theory Practice
WHAT
HOW
WHY

The challenges in this study are as follows:

- **Support planning decision-making tool** for solar energy integration since the early design stages
- **Identify suitable building surfaces**, roofs and facades for BIPV integration.
- **Evaluate and compare the solar potential** of different project scenarios.
- **Optimize the solar energy potential** by controlling their impact on the solar availability of existing buildings.

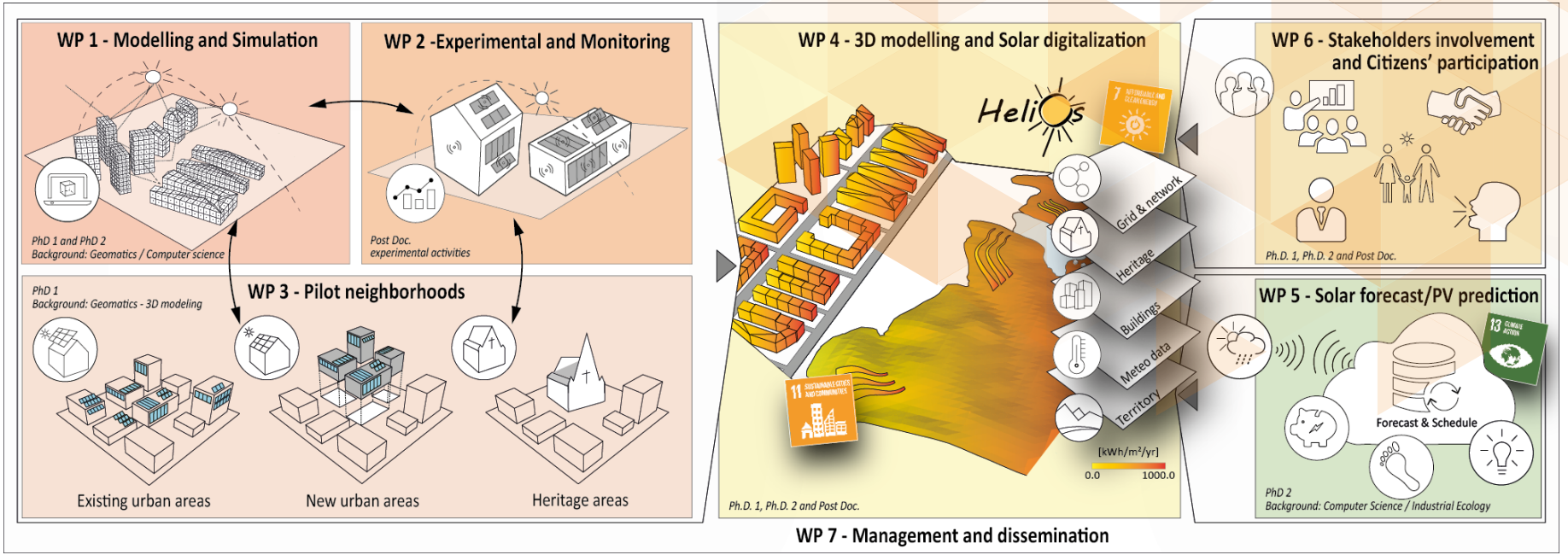
The lessons from the developed workflow are as follows:

- **Avoiding switching between software** will probably be beneficial when it comes to simplicity of methodology.
- Use the **co-simulation approach** by connecting existing tools with pre-algorithms developed through programming languages (eg python, MATLAB Simulink, java, C ++).
- The developed **approach can be replicated** for different building and urban scenarios for multiple design proposals and geographical locations.
- The building archetypes that define the **reduction factors can** also **be replaced** by **building types that are unique to each location**.

Referanse: Lobaccaro, G.; Lisowska, M.M.; Saretta, E.; Bonomo, P.; Frontini, F. A Methodological Analysis Approach to Assess Solar Energy Potential at the Neighborhood Scale. Energies 2019, 12, 3554

HELIOS – NFR Fripro FRINATEK

enHancing optimal ExpLoitatIOn of Solar energy in Nordic cities through digitalization of built environment / Dec. 2021 - Apr.2025

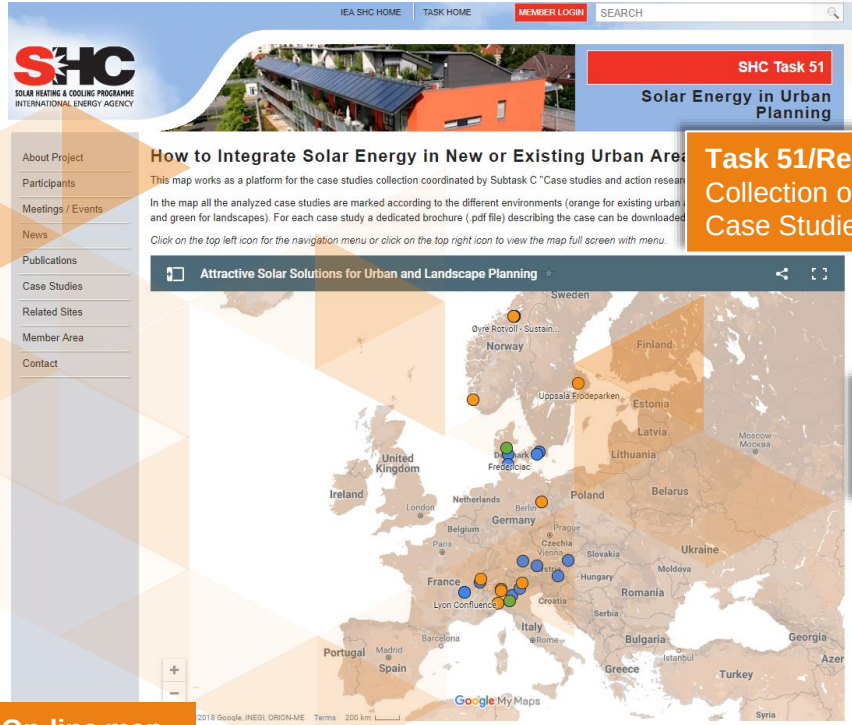


Project owner: *NTNU / IV / IBM*
Project manager: *Ass. Prof. Gabriele Lobaccaro*
NTNU Partners: *IDI, IndEcol, MTP, IMA*
National partners: *SINTEF Community, Trondheim Kommune*

International partners*:*
HEPIA - Geneva School of Eng., Arch. and Landscape – Univ. of Applied Sciences and Arts Western Switzerland;
USMB/INES - University Savoie Mont Blanc / National Institute of Solar Energy (France);
UCB Lyon 1/CETHIL - Claude Bernard University / Centre d'énergétique et de thermique de Lyon (France).

NTNU | Kunnskap for en bedre verden

International activities



On-line map

Task 51/Report C1
Collection of International Case Studies

Task 51/Report C2
National and International Comparison of Case Studies

Task 51/Report C3
Lesson Learnt from Case Studies

Reference: Lobaccaro G., Croce S., Lindkvist C., Munari Probst M.C, Scognamiglio A., Dahlberg, J., Lundgren M., Wall M., A cross-country perspective on solar energy in urban planning: lessons learned from international case studies, (2019), Renewable & Sustainable Energy Reviews , pp. 209-237

Summary

1. Integration of solar cells in building level
   - Case studies of solar system integration - Gløshaugen Campus
   - Optimization of building shape and surface exposure
   - Optimization of solar buildings

2. Integration of solar cells at neighborhood level
   - Solar strategies at the neighborhood level
   - Solar energy from building level to neighborhood level
     - Solar accessibility and solar reflection
     - Overshadowing effect
     - High temperature in cities
     - Solar energy potential

3. International activities

Summary

- Solar energy potential in the Nordic climate is relevant, but it is still untapped
- Solar energy in the Nordic Climate:

Barriers:

- Adverse climatic conditions (?)
- Densification processes
- Urban regulations / Urban planning

Challenges:

- Avoid or control the shading effect
- Control and use the mutual solar reflection

Opportunities:

- Solar strategies at the building and neighborhood level (Solar accessibility,solar reflection, overshadowing effect)
- Increase the solar potential and accessibility of buildings, especially on the facades that are exposed to the north or east (i.e.by using mutual reflections from the ground and the facades) or use Bifacial PV
- Provide guidelines for urban planning of solar energy and preliminary analysis since the early design phases (e.g. District morphology, building shape, materials, etc.) (i.e. Øvre Rotvoll)